Prediction Accuracy of Error Rates for MPTB Space Experiment

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I. SUMMARY

This paper addresses the accuracy of radiation-induced upset-rate predictions in space using the results of ground-based measurements together with standard environmental and device models. The study is focused on two part types - 16 Mb NEC DRAM's (UPD4216) and 1 Kb SRAM's (AMD93L422) - both of which are currently in space on board the Microelectronics and Photonics Test Bed (MPTB). To date, ground-based measurements of proton-induced single event upset (SEU) cross sections as a function of energy have been obtained and combined with models of the proton environment to predict proton-induced error rates in space. The role played by uncertainties in the environmental models will be determined by comparing the modeled radiation environment with the actual environment measured aboard MPTB. Heavy-ion induced upsets have also been obtained from MPTB and will be compared with the "predicted" error rate following ground testing that will be done in the near future. These results should help identify sources of uncertainty in predictions of SEU rates in space.

II. BACKGROUND

It is important to be able to assess ahead of time the possibility of failure of a space mission due to the effects of radiation on the electronic circuits contained on the spacecraft. One threat of particular importance is that of SEU's which, if not considered, may adversely affect mission success. Therefore, it is necessary to be able to predict accurately the SEU rate of electronic circuits in space. Such predictions are typically made by combining ground-based accelerator measurements of SEU cross-sections with models of the expected radiation environment. Programs to calculate SEU rates, such as Space Radiation™, require both cross section data from ground measurements and information about the orbit or the radiation environment.

Recently, Petersen has pointed out that some SEU predictions differ significantly from actual measured SEU rates.[1] These differences may be due to numerous factors including, 1) incomplete information on the angular dependence of the cross-section, 2) the use of COTS parts whose radiation responses vary greatly, 3) incomplete information on the dynamic particle spectrum in space, 4) incorrect models for the ion/matter interactions, including track size, and 5) poor measurement practices, such as using different software and different parts in space and for ground testing.

MPTB attempts to identify the major sources of faulty error rate predictions by eliminating some of the above uncertainties. First, the particle spectrum in space is being continuously monitored to eliminate uncertainties in the environment. Next, to minimize the problems associated with the variable radiation response of COTS parts, identical parts (from the same lot) were used in space and for ground testing. (This does not mean that there were no differences in radiation response, only that they were minimized). Finally, the parts destined for space were mounted on boards *identical* to those used for ground testing and the *identical* software was used in both cases. These measures make it possible to narrow the sources of error to either incorrect models of the radiation environment or to the use of COTS parts. At the same time, the results may be used to evaluate the uncertainties in error rate predictions introduced by the use of COTS parts.

MPTB contains many different part types, including SRAM's, microprocessors, analog-to-digital converters,

artificial neural networks, a fiber optic data bus, and others. Some parts were selected because they were of interest for particular future space missions, whereas others were selected because of their unusual responses to radiation. The two parts we have selected are both memories - one is a NEC (4Mbx4) DRAM and the other is an AMD (256x4) SRAM. The NEC DRAM is of interest for space applications because it is a COTS high-density memory in a plastic package that has not been hardened to the effects of radiation. The selection of the AMD 93L422 SRAM is based on its previously been flown in space on CRRES so that its data can act as a fiduciary point with which to compare the current data because it is known to be very sensitive to proton-induced upsets[2].

The radiation environment to which MPTB is exposed varies significantly with time because the orbit is highly elliptical, dipping below the earth's radiation belts and extending all the way out to geosynchronous orbit. Therefore, during one orbit, the parts are exposed to an intense flux of both protons and electrons in the radiation belts where both SEE and total dose effects occur, as well as to the relatively low flux of highly energetic cosmic rays at apogee, where the primary effects are SEE.
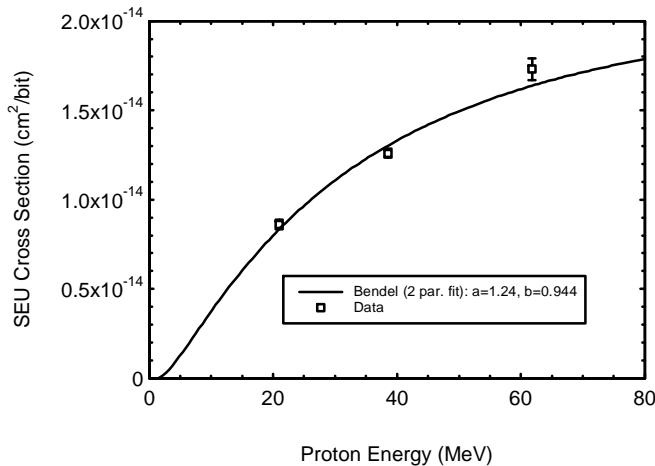

Fig. 1. Proton-induced SEU cross-section as a function of energy for the 16 Mb NEC DRAM.

III. GROUND TEST RESULTS

Proton testing of the DRAM and the SRAM were carried out at Crocker Nuclear Laboratory at the University of California at Davis. Fig. 1 shows the upset cross section per bit for the 16 Mbit NEC DRAM as a function of proton energy. The data has been fitted with a two-parameter Bendel equation which is used together with the proton spectrum at the part to predict SEU rates.[3] The values of the parameters are A=1.24 and

B=0.944. More data at energies above 100 MeV will be collected in order to obtain more precise threshold and asymptotic cross-section values. Fig. 2 shows the proton upset data for the 93L422 which has also been fitted with a 2-parameter Bendel function (A=12 and B=18). Clearly, the fit to the DRAM data is much better than to the SRAM data. Tables 1 and 2 show the results of the error rate predictions using the Bendel one-parameter equation at the energies for the 93L422 SRAM and the NEC DRAM.

Table 1. SEU cross-section, A value, and error rate as a function of proton energy for the 93L422.

Energy (MeV)	93L422		
	Cross Section	A	Error Rate(/bit/day)
21	1.36e-11	15.25	1.5e-3
38.5	5.95e-11	15.44	1.2e-3
63	6.9e-11	16.14	6.6e-4

Table 2. SEU cross-section, A value, and error rate as a function of proton energy for the NEC DRAM.

Energy (MeV)	NEC DRAM		
	Cross Section	A	Error Rate(/bit/day)
21	8.6e-15	20	2.5e-5
38.5	1.26e-14	25.96	4.7e-7
63	1.73e-14	27.91	1.6e-7

Clearly, the one parameter equation does not provide a good fit to the data. Fig.3 shows the cross-section as a function of total dose for the 93L422. Clearly, for doses above about 90 krad(Si), the part appears to be damaged, exhibiting an increase in leakage current and a concomitant increase in error rate. Tests for the DRAM show no change in SEU cross-section up to a dose of
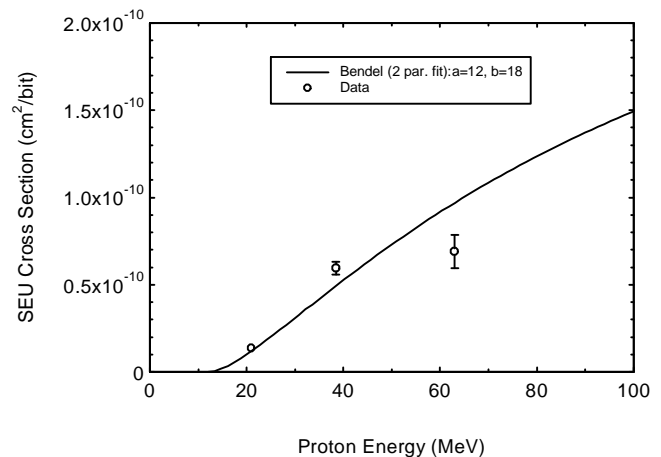

Fig. 2. Proton-induced SEU cross-section as a function of energy for the 93L422 SRAM.

krad(Si). Heavy ion testing of both parts is scheduled for early March, 1998 at which time the dependence of the

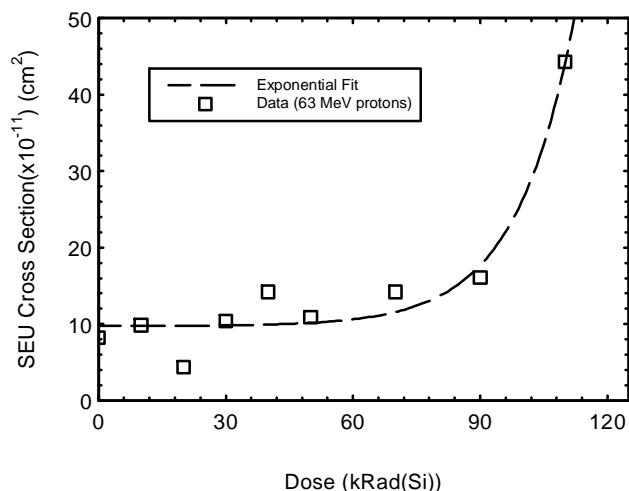cross section on LET at different angles will be measured.

Fig. 3. Proton-induced SEU cross-section as a function of total dose for the 93L422 SRAM.

IV. MODELED RADIATION ENVIRONMENT

The trapped proton and electron environments at solar maximum for the MPTB orbit have been modeled using the UNIRAD code [4]. The minimum shielding thickness for parts on MPTB is the equivalent of 63.2 mils of aluminum for a solid angle of about 2π steradian. The rest of the solid angle is covered by shielding that includes a massive structure and is much thicker. For the minimum shielding, the total dose is predicted to be approximately 50 rads(Si)/orbit. The trapped proton flux with energy greater than 10 MeV behind this shield is predicted to be about 3.4×10^7 protons/cm^2/orbit. For comparison with the ground test data at 20, 40, and 60 MeV, the flux above these energies is predicted to be about 1.7×10^7, 1.2×10^7, and 8.0×10^6 protons/cm^2/orbit, respectively.

The total dose environment at the location of the devices was predicted to be 50 rads(Si)/day. The actual dose rate, which is being measured with MOS dosimeters on each experimental board, is about 18 rads(Si)/day during the early MPTB orbits.

V. ERROR RATE PREDICTIONS

Using the "A" and "B" values obtained from the ground measurements as input to the program Space Radiation (version 4), we find the error rates for proton-induced upsets to be 7.61×10^{-7} errors/bit/day for the DRAM and 1.98×10^{-3} errors/bit/day for the SRAM. The calculation was based on an MPTB-like orbit at solar maximum and 50 mils of aluminum shielding was assumed instead of the actual shielding which is mostly aluminum with a thickness of 63.2 mils. For predicting the upset rate due to heavy ions, we will use the heavy ion spectrum from UNIRAD, the experimental data on cross-section as a function of LET and as a function of angle, and the rectangular parallel-piped (RPP) model.[5]

VI. SPACE DATA

A. Upset Data

The following analysis is for 8 NEC DRAM's on board MPTB. The total number of bits being checked is 128 Mbits (134,217,728) and the devices were loaded alternately with a 1010 or 0101 pattern in each 4-bit word. Because only a limited amount of data is available at this time, the analysis is focused on four orbits (50-53) in December 1997. There were 108 upsets in the DRAM's for an error rate of 4.02×10^{-7} errors/bit/day. For comparison, there were 8 upsets during the same time interval in the two 93L422 devices (with a total of 2048 bits) on the same board for an error rate of 1.95×10^{-3} errors/bit/day. This means that the very old SRAM technology is more than 3 orders of magnitude more sensitive per bit than the modern DRAM technology. [The predicted upset rate for the SRAM shows excellent agreement with the measured upset rate. This is fortuitous given the limited statistics and the fact that the environment was not accurately modeled. For the DRAM, the agreement is not good, even though the fit to the data is better]. The DRAM data exhibited 3 double-bit upsets and one triple-bit upset. These multiple upsets were in bits of the same device but not in the same address and were determined to be multiple-bit upsets based on the fact that they were tagged with the same time. [The probability of more than one particle striking the device in the read cycle time is extremely small.] Bit maps (a scheme relating logical to physical addresses) will be determined using the pulsed laser facility at NRL to determine whether the upsets were physically adjacent, and thus whether they were true multiple-bit upsets. The upsets were evenly divided between $0 \rightarrow 1$ and $1 \rightarrow 0$ transitions based on the fill pattern and addresses. Among the 8 NEC devices, the initial upset data show that 2 were twice as sensitive as the other 6 (to be expected from COTS parts), but the statistics are poor. Further data will be presented in the talk and the final paper.
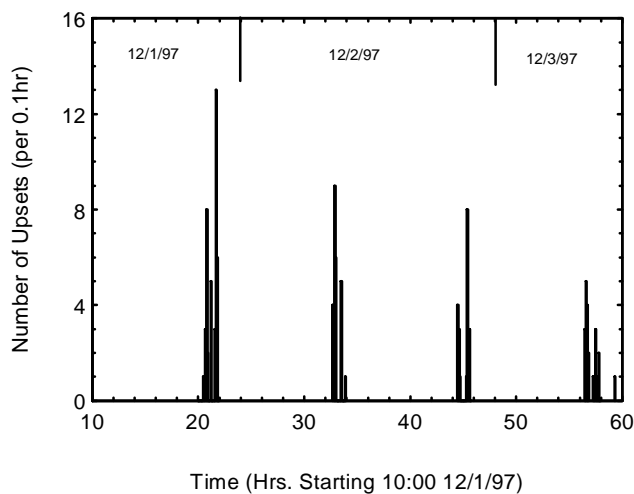
Fig. 4. Number of proton-induced SEU's in 0.1 hr intervals for three days in December 1997.

Fig. 4 shows the number of upsets as a function of time for three days (1st December 1997 - 3rd December 1997). One can see that most of the errors are confined to the times when the satellite passes through the radiation belts: there is one peak when the satellite descends and another when it ascends through the radiation belts. There are also occasional upsets when the satellite is near apogee that are caused by heavy ions. For instance, Fig. 5 shows that on 30th November 1997, there is a multiple bit upset (5 upsets occurring at the same time) due to a single heavy ion. From the logical addresses of the upsets alone, it is not possible to tell whether the cells are in a cluster or whether they form a long line. The former case
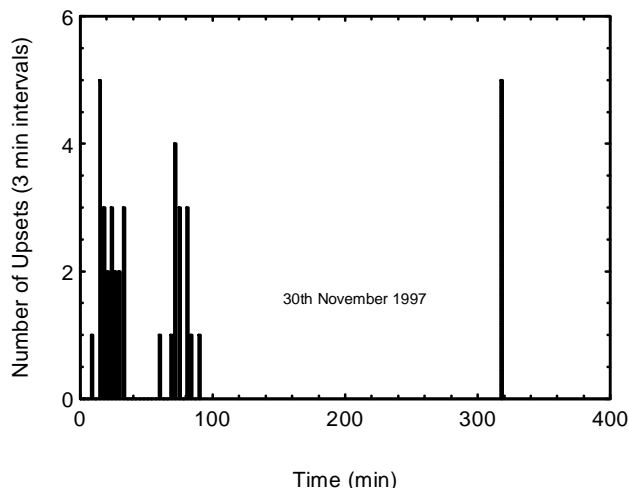

Fig. 5. SEU's in the DRAM for one day. The two periods during which many upsets occurred are for the times when the spacecraft passed through the proton belts. The single peak at 230 min. is due to a single heavy ion that produced 5 upsets simultaneously.

would be due to a large diameter track from a highly energetic heavy ion encompassing many memory cells,

whereas the latter would be from an ion traveling almost parallel to the surface of the device and passing through many memory cells. The bitmap will assist in answering this question. The heavy-ion induced SEU data is currently being analyzed.

B. Environmental Data

The environmental data will be obtained from the space particle telescope on board MPTB provided by The Aerospace Corp. The measured environment will be compared with the modeled environment and the differences will be used to make corrections to the predicted SEU rates. This will eliminate one in the list of contributions to the uncertainties in error-rate predictions previously mentioned.

VII. CONCLUSIONS

At this time it is impossible to make any definitive conclusions because vital parts of the data are not yet available and the preliminary calculations are based on some approximations. However, by monitoring the radiation environment in space, by using identical parts, boards, and software in space and for ground testing, and by doing careful measurements of heavy ion cross-sections as a function of angle, it will be possible to identify the current shortcomings in the SEU rate predictions for space.

VIII. REFERENCES

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